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HIGHER ORDER SCATTERING IN THE TWILIGHT SKY ZENITH

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SUMMARY

It is shown in this note that since the influence of higher order scattering at zenith of the twilight sky may be quite significant by comparison with the brightness of primary twilight at the same point and dependent to a high degree on the assumed atmosphere structure, any judgement on the optical properties of the atmosphere on the basis of the quantity B(0, 0) is entirely void of ultimate significance.

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During the sounding of optical properties of the atmosphere by the twilight method the scattering of higher orders, which cannot be separated from the observation themselves in the zenithal region of the sky, is usually underestimated. For this reason we conducted the theoretical calculation of that effect in the assumption that the scattering of light (performed by the terrestrial atmosphere) follows the exponential law for heights of uniform atmosphere respectively of 10 and 20 km. As is well known, for a sufficient Sun's dipping under the horizon, namely not less than 6°, the primary twilight segment is separated from the troposphere above the observer by a large distance, and thus may be considered as a certain external light source. In this case, which is of greatest interest, the illumination produced by this partially polarized segment in zenith may be represented by the expression

$$I(0,0) = \frac{\mu}{\tau}\iint B(z, A)\, f(\vartheta)\, \varphi(z, 0)\, (1 + PP_0 \cos 2\alpha) \sin z \, dz \, dA,$$

where B(z, A), P_0 are respectively the brightness and the polarization of the primary segment at the point with coordinates z, A; $f(\vartheta)$ is the tropospheric scattering indicatrix, found directly from observations with its polarization component f_1 and f_2 [1]; α is the angle at (z, A) between the directions at

(*) O RASSEYANII VYSSHIKH PORYADKOV V ZENITE SUMEROCHNOGO NEBA the Sun and the zenith; τ/μ is a dimensionless quantity, equal to

and, finally,
$$2\pi\int_0^\pi f(\vartheta)\sin\vartheta\,d\vartheta$$

$$\varphi(z, 0) = \frac{p - p^{\sec z}}{\sec z - 1}, \quad P = \frac{f_1 - f_2}{f_1 + f_2}$$

p being the index of transparency.

A rigorous expression for B(z, A) must account for the refraction of light rays in the atmosphere, the so called refraction dispersion, and the finite dimensions of the solar disk, and also the scattering indicatrix, precisely inherent to high atmosphere layers and characteristic of aerosols, but not of the standard gas component. For the calculations indicated we utilized a simpler expression, without taking into account the refraction, namely

$$B(z, A) \sim \frac{f(\vartheta)}{\sin\vartheta}\int_{h_{0\,min}}^{\infty} \mu(h)\,[1 - e^{-K(h_0 - B)^2}]\,dh_0,$$

where the expression, standing under the integral sign in brackets, accounts for approximately the lower atmospheric layer-produced extinction of solar rays passing at minimum distance h_0 above ground, and $\mu(h)$ is a function of scattering, depending upon the altitude and taken, as already indicated above, in the form $\mu(h) = e^{-h/H}$, where H = 10 km, H = 20 km. It is empirically obtained that K = 0.004 and B = 9 km.

The relation between the parameter h_0 and the altitude h of the scattering atmosphere element may be found for any point of the sky (z, A) and for any zenithal distance of the Sun ζ over the entire extension of the visual ray, and then, utilizing the aerosol component of the scattering indicatrix, and the brightness of the twilight segment may be computed. For brevity we bring forth here the intensity distribution only for various points of solar vertical in conditional units (see Table 1 hereafter).

lg $B(z, A)$ TABLE 1

tg z	$\zeta = 96°$		$\zeta = 98°$		$\zeta = 100°$		$\zeta = 102°$		$\zeta = 104°$	
	H = 10 км	20 км	H = 10 км	20 км	H = 10 км	20 км	H = 10 км	20 км	H = 10 км	20 км
0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
1	0,636	0,520	0,799	0,595	1,112	0,729	1,545	0,922	2,090	1,256
2	1,219	1,022	1,510	1,154	2,[illegible]10	1,374	2,629	1,695	3,532	2,160
4	1,929	1,668	2,363	1,805	3,[illegible]62	2,115	3,927	2,549	5,498	3,147
10	2,780	2,200	3,374	2,538	4,2[illegible]8	2,9[illegible]9	5,369	3,464	6,830	4,183
∞	3,716	2,963	4,482	3,276	5,598	3,770	6,892	4,385	8,549	5,185

For an exemplary calculation of higher order scattering we shall point out that, as indicated by tentative computations, the accounting of the polarization P_0 alters the result only by a few percent, and is thus not compulsory. Utilizing the standard tropospheric scattering indicatrix, assuming that the index of atmosphere transparence is p = 0.835 and finding for the ratio

$\tau/\mu = 17.78$, we obtain for the point of the zenith the following ratio of higher order scattering (troposphere component) I(0, 0) to the intensity of primary twilight at the same point B(0, 0) (see Table 2).

TABLE 2

$I(0, 0)/B(0, 0)$ $(z = 0)$		
ζ	$H = 10$ км	$H = 20$ км
96°	0,96	0,31
98°	—	0,50
100°	32,7	1,08
102°	—	3,81
104°	13 000	13,44

As may be seen, the influence of scattering of higher orders in the zenith of twilight sky may be quite significant by comparison with the brightness of primary twilight at the same point, and it may to a high degree be dependent on on the assumed structure of the atmosphere.

Hence it follows that the observations of twilight sky at zenith are totally devoid of ultimate significance for the judgement of optical properties of the atmosphere on the basis of the quantity B(0, 0).

***** THE END *****

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